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Review

COVID-19 PANDEMIC: THE ROLE OF RISK FACTORS RELATED TO URBAN SPACE (ANALYTICAL REVIEW)

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Comfortable urban environment plays a key role in protecting health of people residing in large urban settlements. At the same time, urban space has some peculiarities including high population and building density, imperfect traffic infrastructure, irrational planning decisions, elevated levels of ambient air pollution, heat islands and lack of urban green spaces. All these features of any urban space are significant health risk factors able to facilitate spread of respiratory diseases. This was the most evident during the COVID-19 pandemic. The analytical review examines the results of studies focusing on impacts exerted by these unfavorable urban conditions on COVID-19 infection, incidence, hospitalization and mortality in cities across the globe.

Influence of elevated population density on COVID-19 infection is shown to be ambiguous as compared to other risk factors. More reliable data are available on the impact of air pollutants, especially PM, on incidence and mortality rates from the infectious disease in question. Also, the COVID-19 virus and abnormally high temperatures were shown to produce combined effects on mental health during the pandemic.

To reduce levels of infection in urban population, a suggestion is to further develop urban infrastructure providing people with retail and other necessary facilities within a walking distance (15 minutes). An important conclusion has been made by experts on elevated risks of infection in dense foot traffic as compared to public buildings. Therefore, it is important to improve communications about the necessity of social distancing. Urban development that aims to reduce infection with respiratory diseases should involve better street aeration. The results of these studies in various cities across the globe gave grounds for making management decisions on providing better mobility in suburban areas in a more comfortable natural environment, developing green areas in cities, and reducing negative effects of the warming climate on heat islands and elevated levels of ambient air pollution. Large open green spaces are the most effective in this respect.

Keywords: *COVID-19, population health, health risks, public health, green spaces, city planning, territorial planning, urban planning, megacities.*

Cities are drivers of the economy. They provide access to employment, opportunities and resources. Forecasts suggest that approximately 70 % of the global population is going to live in cities by 2050. Population also grows steadily in Russian megacities, that is, cities where population exceeds 1 million people. It was in cities where the COVID-19 pandemic brought about the most drastic changes; that is, where a colossal social experiment took place as regards changes in urban planning [1]. Since 2022, Lancet Global Health has been publishing works that explore various aspects of urban planning and population health and touch on issues related to spread of respiratory tract infections. Results obtained by interviewing experts on atypical pneumonia have confirmed that respiratory tract infections spread more rapidly now than ever before [2]. According to the WHO, approximately 702 million people got infected during the COVID-19 pandemic and 7 million died from it in the world. Many facts provide solid evidence of the association between urban planning and population health as reported in several reviews [3, 4]. Health issues as regards urban residents have become an important aspect of new urbanism. A new concept of healthy Urban Planning has occurred; it involves integrating various aspects of healthcare into poli-

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cies and practices within urban development. The United Nations Human Settlements Programme (HABITAT) and the WHO published a sourcebook on integrating health and territorial planning. It covers environmental protection; hygiene and sanitary, including injury prevention; healthy lifestyle promotion and physical activity[1]. Issues of such planning are extremely relevant for our country as well, primarily, considering elevated population density in some cities [5], imperfect transport infrastructure, ongoing high-rise development in small areas, poor quality of the environment and consequences of the pandemic, which affected the demographic situation in Russia.

According to Rosstat reports, excess mortality amounted to 749.5 thousand cases in Russia during the pandemic in 2020–2022. Demographists concluded that this excess mortality resulted in reduction in life expectancy in 2020, by 2.33 years among men (5 % CI: 2.17–2.027) and by 2.13 years among women (95 % CI: 2.03–2.25) [6]. For reference, it is worth mentioning that the absolute number of deaths was higher than 1 million in the USA but the intensive rate was 1.6 times higher in Russia. Clearly, such data should be considered tentative since infected people died due to other causes without being diagnosed with the coronavirus infection. In 2021–2022, higher COVID-19 incidence was typically reported among urban population in Russia in comparison with rural residents (1.5–1.8 times) [7]. We can assume that this is to a certain extent due to much smaller scopes of health check-ups in rural areas that used up-to-date methods for estimating actual spread of the COVID-19 virus. The standardized mortality rate is more informative when it comes down to assessment of the pandemic outcomes. It indicates a rather different situation since it was approximately the same in 2019–2021 but 1.06 times higher among rural residents in 2022[2]. This can obviously be explained by depleted resources of the healthcare system in rural areas, including partial transfer of healthcare workers to urban areas.

There are hundreds of thousands of works in the literature that concentrate on assessing impacts of various risk factors on the pandemic. A considerable part of them focuses on peculiar development of the pandemic in urban environment. A search in PubMed using keywords ‘COVID-19 and urban space’ shows more than 500 articles on the subject. This review analyzes two risk factors, population density and ambient air pollution, as well as such a compensatory indicator as urban green spaces considering the socioeconomic reality and quality of the environment in Russian cities.

COVID-19 and population density. Different morphology of urban development might have affected the pandemic dynamics. Some available studies concentrate on factors associated with building density. The COVID-19 outbreak put issues associated with compact urban development to the forefront. An initial hypothesis was that densely populated areas with developed transport infrastructure could become hot points of the rapid pandemic spread due to high estimated personal interactions. First publications of 2020 about an outbreak in Wuhan reported associations between COVID-19 cases and high population density [8, 9]. This was evidenced in Beijing and other Chinese cities [10, 11]. Evidence of the association was also reported in other countries including Canada [12], Japan [13], and Italy [14]. Analysis of influence exerted by population density established it to be the strongest predictor of variation in incidence rates practically in all American states [15]. Although high population density can be a factor that facilitates transmission of communicable diseases, cities with high population density are often much better prepared for infection outbreaks and

[1] Integrating health in urban and territorial planning: a sourcebook. Geneva, UN-HABITAT and World Health Organization, 2020, 108 p.

[2] According to Rosstat.

have better access to resources necessary for timely responses to prevention of virus spread. On the contrary, rural areas and suburbs with low population density have limited access to such resources [16]. In addition to that, it is much more difficult to keep social distance in urban areas with high population density and in overcrowded places.

In developed countries, healthcare is high qualitative both in urban and rural areas and healthcare facilities are available to all residents. It happens so in the Netherlands where COVID-19 infection, hospitalization and mortality were established to have no clear correlations with the population density or urbanity of the municipality [17]. Higher death rates were observed in rural areas in developing countries, especially among older age groups, due to underdeveloped healthcare systems and long distances to hospitals[3].

Changes in the urban environment as a response to the pandemic should go well beyond some narrow concepts of population density and rely on more profound investigation and a more subtle insight into such urban aspects as interrelation, uneven development, overcrowding of residential buildings and poverty. The COVID-19 issue in the urban environment requires a broad discussion of various population density types. The pandemic can 'stimulate instant re-think of how we plan and build our cities and get to know them'. It is necessary to revalue population density [18]. This postulate is further supported by the results of studies with their focus on COVID-19 mortality in 900 large counties in the USA where no strong positive correlation was found between COVID-19 spread and mortality rates and population density [19]. The same author reported in his other study that crowding around sights rather than population density facilitated the SARS-CoV-2 virus spread in New York, the largest city in the USA [20]. A study [21] reported that high population density had no effect on COVID-19 mortality in Chicago, another American megacity. Investigation of effects produced by various density measures on COVID-19 incidence and mortality rates established a more significant role of *job density* in all urbanized American counties. The authors also mention some controversy in conclusions about density and the disease spread due to different density measures utilized in different research works [22].

In urban environment, as exemplified by New York [23], differences in easy access to critical infrastructure objects are an important factor that can explain spatial disproportions in the virus spread in specific areas in this city. The study covered density measures, distances to public places, distances to healthcare facilities, distances and access to transportation hubs. To reduce levels of infection in urban population, a suggestion is to further develop retail, entertainment and other infrastructure within a 15-minute walking or cycling distance. This will provide higher quality of life for urban population [24]. Large cities usually have complex infrastructure networks and developed healthcare facilities and a compact city structure provides easier access to healthcare services. Therefore, a developed infrastructure and higher compactness of the urban environment have been shown as able to overcome infection outbreaks and mitigate their negative influence on population health [19, 25–27].

More profound examination of urban structures in Amsterdam and COVID-19 infection among residents established a higher risk of infection in streets with high estimated pedestrian flows. It is such streets where social distancing between residents is mandatory for reducing airborne transmission of infections. Streets with high pedestrian flows are more risky as regards infection than crowds in public places [28].

[3] Dobis E., McGranahan D. Rural death rates from COVID-19 surpassed urban death rates in early September 2020. *Economic Research Service of U.S. Department of Agriculture*, 2021. Available at: https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=100740 (January 19, 2024).

A study that investigated excess COVID-19 mortality in Russian regions did not establish any effects produced on it by population density [29]. Still, such effects were reported among shift workers in Khanty Mansi and Yamal Nenets Autonomous Area as well as among retired people who lived in board and care homes [30, 31].

COVID-19 and ambient air pollution. Particulate matter in ambient air creates clusters with coronavirus particles and together they spread over a 10-meter distance from an infection source. A certain similarity exists between effects of the SARS-CoV-2 virus and exposure to fine dispersed particles sized less than 10 μm (PM_{10}). We considered the issue in great detail in our previous review [5] that summarized the results reported in publications on the subject in various countries across the globe by 2020. More than 30 studies accomplished in China, India, Italy, Spain, Germany, and France provide evidence of correlations between COVID-19 incidence and death rates and levels of ambient air pollution. After 2020, new research works on the issue have been published and they also confirm the foregoing correlations [32, 33]. Up to 6.6 % of COVID-19 deaths in Europe and up to 11 % of such deaths in China were caused by ambient air pollution. People with chronic lung diseases exposed to higher $PM_{2.5}$ levels were much more frequently hospitalized due to COVID-19 and this indicates exacerbations of a basic disease [34]. $PM_{2.5}$ particles and other pollutants aggravate the disease by making epithelium more permeable and stimulating expression of ACE2 receptors in the airways. They also induce oxidative stress, stronger inflammatory reactions and immune deregulation [35–37].

In Russia, a relationship between COVID-19 incidence and ambient air pollution was explored in six cities (Bratsk, Lipetsk, Krasnoyarsk, Norilsk, Omsk and Cherepovets) with the Clean Air Federal project. A growth by 5.0 ± 2.6 % in mean excess COVID-19 incidence against the 'baseline' epidemic scenario was proven in these cities over 14.5 months of the pandemic [38].

Since solid evidence of the association between pollutant (PM and nitrogen dioxide) concentrations in ambient air was published quite promptly in 2020, some countries, Russia included, introduced certain limitations on pollutant emissions and they actually went down a bit. Levels of ambient air pollution declined in Moscow as well [39, 40]. Overall, according to various estimations, reductions in emissions varied between 4 and 7 % across the globe during the pandemic [41].

COVID-19 and heat islands in cities. Intense climate change has resulted in elevated health risks due to exposure to extremely hot temperatures on heat islands in cities. This is especially apparent in areas with high-rise development. This phenomenon in Russian cities has been investigated by climatologists for a long time and their occurrence has been established not only in large cities but also in smaller ones, for example, in Nadym (46,000 residents) [42]. In addition to heat islands, a humidity island or a wind island can also occur in city centers. The former is due to absence of any open soils and the latter is formed due to high-rise buildings when air tends to flow turbulently around them. In summer, a mean air temperature can be 2.1–5.5 °C lower around lawns than around impermeable surfaces. All these factors make climate in a city center even more uncomfortable. For example, when this situation was simulated in 30 largest cities in the country, heat islands with a 'feels like' temperature above 50 °C were established in the center of Krasnodar[4] [43]. Even short heat waves, 3–5 days long (that are practically unavoidable in summer in moderate continental climate), lead to 4.5 time in-

[4] Apparent temperature, also known as "feels like", is the temperature equivalent perceived by humans, caused by the combined effects of air temperature, relative humidity and wind speed. The measure is most commonly applied to the perceived outdoor temperature.

crease in the number of complications in cardiovascular patients [44], that is, an additional threat occurs for COVID-19 patients. Also, combined exposure to the COVID-19 virus and extreme heat pose a serious threat for mental health as confirmed by many Russian and foreign studies. A review of works published in Russian language about anxiety and depression-like disorders and growing suicide behavior during the pandemic can be found in [45, 46]; the same mental disorders during heat waves are discussed in our scientific report [47].

However, a drop was reported in air temperature during the pandemic due to some reductions in pollutant emissions and anthropogenic heat. This situation occurred in 46 Chinese cities [48] and in business districts in Osaka (Japan) owing to 75 % of personnel working remotely [49]; squares of heat islands were the smallest over the whole observation history in Casablanca City, Morocco [50].

Interactions between PM pollution in ambient air and ultraviolet radiation (UVR) are another interesting issue. A decrease in PM levels in ambient air can result in a growth in such radiation. Elevated UVR doses are known to affect the immune system, skin and eyes and this factor might also have aggravated the clinical course of COVID-19 in some Russian regions. On the Russia territory, erythema-inducing UVR is monitored at 14 stations of Rosgidromet as well as by some scientific research institutions and the Department for Climatology and Meteorology of the Geographical Faculty of the Moscow State University. Personnel of this Department have developed a very interesting indicator called 'UV-resources'. It allows estimating positive and negative effects produced by this factor on different skin types and eyesight. Use of an algorithm for assessing hazardous UVR doses made it possible to determine territories with the highest health risks. They are northern and eastern regions predominantly in spring [51]. People who live in these regions are also exposed to an additional health risk when they move to the south or spend their vacation in southern countries. UVR levels harmful for health are also observed in southern regions between May and August with 20–25 % frequency and in mid-latitude regions with frequency between 5 and 12 % [52]. Excess UVR also occurs due to the ozone layer depletion, especially in some years above the Arctic zone. Recent studies have reported excess UVR levels due to ozone holes above the southern and central Volga region, Urals and Western Siberia [53].

COVID-19: the role of green spaces in physical and mental health protection. The COVID-19 pandemic provides a unique opportunity to get a better insight into a role of urban development strategies in making city communities more resistant to the pandemic, including green spaces as their most significant element. Studies accomplished in many countries have provided evidence of how important green spaces are for population health, for mitigating outcomes of social isolation and for mental health protection both during the pandemic and after it [54–62]. A study in China has established that people who visited a park in Beijing at the height of the pandemic were much more positive when posting in their micro-blogs inside the park than beyond it; park landscapes and greens were the basic elements able to stimulate positive emotions. Physical activity decreased to a lesser extent among people living in greener districts than among those who lived in places with smaller green spaces. During the pandemic, urban green spaces promoted physical activity among people especially those who lived in areas with larger green spaces [63, 64].

However, parks could be visited by infected people as well in cities without extremely strict limitations on moving around [65, 66]. An interesting expression 'pocket parks' was used by sociologists in a social survey conducted among New York residents during the pandemic. A pocket park is a small

space, which we usually call a square, where urban residents can have a short rest. They were very popular during the pandemic. Nevertheless, large urban green spaces are much more effective. The WHO recommends having a green space with a square not less than 0.5–1 hectare within a 300-meter distance from apartment buildings [67]. During 2021 summer heat in Moscow, the most prominent cooling impact was exerted by an 'urban forest' with its square being 250 hectares where a breeze effect occurred [68].

An interesting retrospective study focused on relationships between COVID-19 frequency (individual data with a positive test) and a place of residence during the start of a vaccination campaign [33]. Created multidimensional models revealed a higher hospitalization risk (14.2 %) for people living in apartment buildings against those living in private houses. This study, similar to some others [61, 69–71], also pointed out it was important to assess influence of a development structure that facilitates greater population mobility. Living in an area more suitable for walking and cycling reduces a hospitalization risk for people with COVID-19.

Conclusion. It is a very difficult task to analyze influence of many overlapping risks present in the urban environment on COVID-19 prevalence and outcomes. These risks include high population density, ambient air pollution and heating climate (against background effects produced by a set of socioeconomic and biological factors). But this task should be solved if we want to determine what further tasks need solution in order to improve an epidemiological situation concerning respiratory tract infections. Moreover, at present there are no studies with some solid results on COVID-19 infection in Russia on territories with high levels of ambient air pollution near metallurgical and chemical plants, ore mining and processing enterprises and other productions.

It is very difficult to describe and estimate the colossal set of socioeconomic outcomes of the pandemic, which are going to be felt over the forthcoming years. Some population groups faced reductions in their incomes during the pandemic. Economists from the Financial University under the Government of the Russian Federation [72] assessed effects produced by the number of COVID-19 cases on real population incomes in Russian regions in 2020 against their level in 2019. An authentic relationship was established (the Pearson's test value is 0.42) that the greater number of diseased meant the greater reduction in incomes. As the authors of this study put it, 'the disease washes workers out from economic processes for 2–3 months' and this leads to a reduction in the regional gross product and lower living standards. Unfortunately, economic losses caused by the pandemic have not yet been estimated, either at the national level or in specific regions. We can give one example of Norilsk where Nornickel Company spent approximately 12 billion rubles on fighting against the pandemic in 2020 including additional equipment provided for the healthcare system in the region (artificial ventilators, reanimobiles, and thermal viewers).

The COVID-19 pandemic caused a drop in life expectancy at birth, a basic demographic indicator, together with an increase in mortality among working age people. Analysis of this indicator as per age groups over 2000–2021 revealed that the pandemic disrupted a stable descending trend observed for mortality in this age group. Mortality rates grew among young people (aged 15–29 years) as well and this is rather uncharacteristic for economically developed countries. Mortality grew among young and middle-aged people against the previous year even in 2021 when mass vaccination was already taking place. The 2019 survival curve highlights an extremely negative trend: 29 % of men and 11 % of women will not reach the age of 60 years [73]. The pandemic had a negative effect on birth rates as well due to postponed pregnancies and IVF, fewer conceptions due to a fear of infecting a fetus and some other reasons [74].

Many experts on public health, urban planning and development have analyzed the

COVID-19 spread in cities and suggested various solutions how to mitigate environmental health risks for urban residents and to reduce prevalence of respiratory infections. Unfortunately, urban planning in Russia completely neglects such morphological indicators as block orientation, street height to width ratios, building density etc. When they are used correctly, better aeration is provided in a city. Therefore, it is important to study concrete proposals on urban planning and development introduced in other countries in the post-COVID period. The COVID-19 pandemic has made open public spaces in cities much more important and highlighted the necessity to evaluate planning decisions in a different way preventing any concentration of multi-storey buildings on a limited spot. More and more urbanists and experts on urban development believe it is necessary to gradually move from vertical urban design to horizontal one. This will make the urban environment more comfortable and provide an opportunity to promote population health [75–78].

Another suggestion is to change rules for planning urban public spaces and make them more suitable for keeping a social distance on benches, in typically overcrowded places, at public transport stops and other similar locuses [79]. It is also necessary to drastically increase open green spaces based on scientifically grounded benefits for health risks mitigation provided by both large and smaller green areas [47]. It is very important that now some findings are available on better stress management of people who interact with green spaces in daily manner [80]. Therefore, it seems necessary to search for a balance between such small green spaces and a need in large ones in megacities. Even indoor green spaces had certain positive mental effects during the pandemic quarantine [81]. Urban green spaces replaced various outdoor activities due to their accessibility and availability as gathering places for small numbers of people while maintaining social distancing. An unusual term, ‘spatial vaccine’, was suggested for such places [82]. Urban planning that considers such health risks as heat islands and poor ambient air quality should also be aimed at preventing risks of respiratory infections, COVID-19 included [83, 84].

A year after the pandemic started bringing about high excess mortality in large cities, leading European public health experts pointed out the necessity to improve urban planning and to decrease traffic flows. To make a step towards it, the city of Barcelona has introduced the Superblock model, wherein motorized traffic is discouraged and active transportation and green space are encouraged [85]. London introduced low-traffic neighborhoods, where motorized traffic is discouraged and people activities are encouraged. Paris is introducing the 15-min city, where all kind of destinations, work, school, shops, culture and leisure facilities should be reached within a 15-min walk or bike ride from home. Hamburg City is planning to make some blocks car-free by the year 2034 [86]. Decisions on necessary changes in urban planning were made in 89 cities across the globe during the pandemic and 63 cities decided to improve people mobility and traffic flows. For example, new bike paths were built in Bogota, the capital of Columbia with approximately 8 million of population [87]. These new urban models all aim to provide more public space for people and less space for individual motorized traffic and thereby to reduce air pollution and noise levels, greenhouse gas emissions, and heat island effects and increase physical activity of urban residents. To achieve this, key activities will include reaching scientifically grounded density, which does not create additional health risks, makes necessary destinations easily available and provides a walking distance to public transport and green spaces. Urban green spaces within a 15–20 minute walking distance increase life expectancy, improve cognitive functions in children and elderly people, promote mental health and stimulate the immune system [88].

Considerable experience in rational urban planning that takes health protection into

account has been accumulated in Russia as well. Mathematical modeling of building density and traffic networks is widely used in many Russian cities to make optimal planning decisions aimed at minimizing population health risks caused by ambient air pollution and elevated noise levels[5] [89–93]. Constantly growing intensity of traffic flows in cities requires special attention to be paid to hygienic assessment of projected changes in traffic infrastructure. A multi-level model for calculating emissions of 18 pollutants, which is integrated into the COPERT V software, has been created exactly for this purpose. Using it made it possible to identify areas with elevated ambient air pollution in Moscow [94]. Hygienists and urban planners cooperated to make optimal decisions on creating a comfortable living environment in urban blocks considering building height and density and urban planning techniques [90]. Our previous review [95] also focused on recommendations given by Russian hygienists on how to plan residential areas considering health risk mitigation. If followed, these recommendations provide protection from high wind speed and bioclimatic comfort. Green Ur, a new software product developed by the WHO Regional Office for Europe is also very eligible for assessing influence of green spaces on population mortality and mental health. Specific measures aimed at adapting city management to climate change have been considered in depth in Changing Climate and Population Health: Adaptation Issues (scientific report) made by the Institute for National Economy Forecasting of the Russian Academy of Sciences [47]. An energy transition from fossil fuels to renewable energy sources, which is being conducted by many countries at the moment, is also aimed at decreasing air temperatures. It will not only make our cities more stable but also help provide a more comfortable living environment and promote population health.

Effective measures for promoting health of people living in megacities and other large urban settlements include better planning of residential areas with more spaces provided for walking and cycling and more developed pedestrian and cycling infrastructure; encouraging mixed land use; lower building density. To achieve greater population mobility is an extremely complex management task; finding a solution to it requires participation of a wide range of experts, from teachers to urban developers. The pandemic can be considered the most significant starting point for speeding up creation of a comfortable urban environment. These goals are stipulated within the Climatic Doctrine of the Russian Federation approved by the RF President Order issued on October 26, 2023; the National Plan on Adaptation to Climate Change; Clean Air and Comfortable Urban Environment Federal projects. Still so far there have not been any new decisions made in the country in urban planning and development of available urban green spaces.

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